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Title: MECHANISTIC ANALYSIS OF GLOVEBOX FIRE PROPAGATION

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Submitted to: 1999 Safety Analysis Workshop
June 13–18, 1999
Portland, OR



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# Mechanistic Analysis of Glovebox Fire Propagation


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## ABSTRACT

Propagation of a fire that originates in a single glovebox to other locations in the Plutonium Facility at Los Alamos National Laboratory is conceivable only if transport of hot combustion gases to other locations causes ignition of combustible materials elsewhere in the system (i.e., flashover). This paper describes a model developed, using the MELCOR computer code, to calculate the generation and transport of combustion gas mass and energy during postulated glovebox fire accident scenarios. The accident scenarios involved a wide spectrum of glovebox operating and potential fire conditions to determine whether flashover conditions could occur at locations outside the burning glovebox:

- A variety of combustible material characteristics was considered (e.g., type, quantity, and combustion properties of combustible material).
- A spectrum of safety system operating conditions was considered (e.g., glovebox ventilation system operating normally vs an inoperative exhaust fan; drop-box fire damper closure vs failure to close).
- A range of analytical modeling assumptions was considered (e.g., the extent to which heat transfer between hot combustion gases and the glovebox walls is represented in the model).

Example results of these calculations are presented to illustrate the benefits obtained and lessons learned by using a computational tool like MELCOR for this analysis.


## INTRODUCTION

The lessons learned from two major glovebox fire events in the 1950s at the Rocky Flats Plant led to several improvements in the design features of the glovebox system in the Plutonium Facility at the Los Alamos National Laboratory, which was built in the 1970s. First and foremost is the replacement of the glovebox and conveyor system Benelex/Plexiglas enclosure with (noncombustible) stainless steel. Because Benelex and Plexiglas are combustible materials, growth of the fire along the flammable walls of the glovebox and conveyor system was the principal mechanism by which the fire propagated in the Rocky Flats fires. This possibility was eliminated in the design of the glovebox system at PF-4 by building the walls with stainless steel.

Nevertheless, propagation of a fire that originates in a single glovebox to other locations in facility is conceivable if a sufficient quantity of hot combustion gases are transported to other locations in the facility. That is, if the temperature of a neighboring area can be raised high enough, combustible materials may be ignited, effectively propagating the fire. This paper describes an effort to model the PF-4 glovebox system, the associated ventilation system in PF-4, and their collective performance in response to a wide spectrum of postulated glovebox fire accident scenarios.

## DESCRIPTION OF THE PF-4 MODEL

A wide variety of chemical, metallurgical, and machining processes is performed within glovebox systems in PF-4. In one section of the building, the processes focus on plutonium research and development or $^{238}Pu$ operations. Processes conducted in another section include material recycling, metal preparation and fabrication, and nondestructive analysis. Although the details of glovebox contents and associated hazards vary considerably among these areas, the basic system configuration is very similar. Consequently, the scope of the PF-4 glovebox model was constrained to the gloveboxes and supporting components in two neighboring rooms in one representative area of the building.

Each glovebox, trunkline, and drop box in these rooms is represented in the model, allowing temperature and pressure distributions to be calculated at a level of detail consistent with normal system operations. In addition to these components, portions of the dry air supply tunnel and glovebox exhaust header that pass through the rooms are modeled, are their connections to supporting Zone 1 ventilation components in the building basement. These components are shown in Fig. 1, which identifies the boundaries of the PF-4 glovebox model.

The laboratory rooms themselves also are modeled with a simplified representation of the laboratory ventilation system. The model for laboratory ventilation does not distinguish recirculation from bleedoff ventilation flow nor is the south section corridor explicitly represented in the model. Rather, the model uses a single aggregate exhaust fan to draw air through each room at a rate that corresponds to the net room air changeover provided by the ventilation system (i.e., ~6 per hour).

### Computer Code Used

The PF-4 glovebox system model was developed as input to the MELCOR computer code [1]. MELCOR is a generalized, lumped-parameter, thermal fluid-analysis code originally designed for the analysis of postulated accidents in commercial nuclear reactors. However, major code modules that

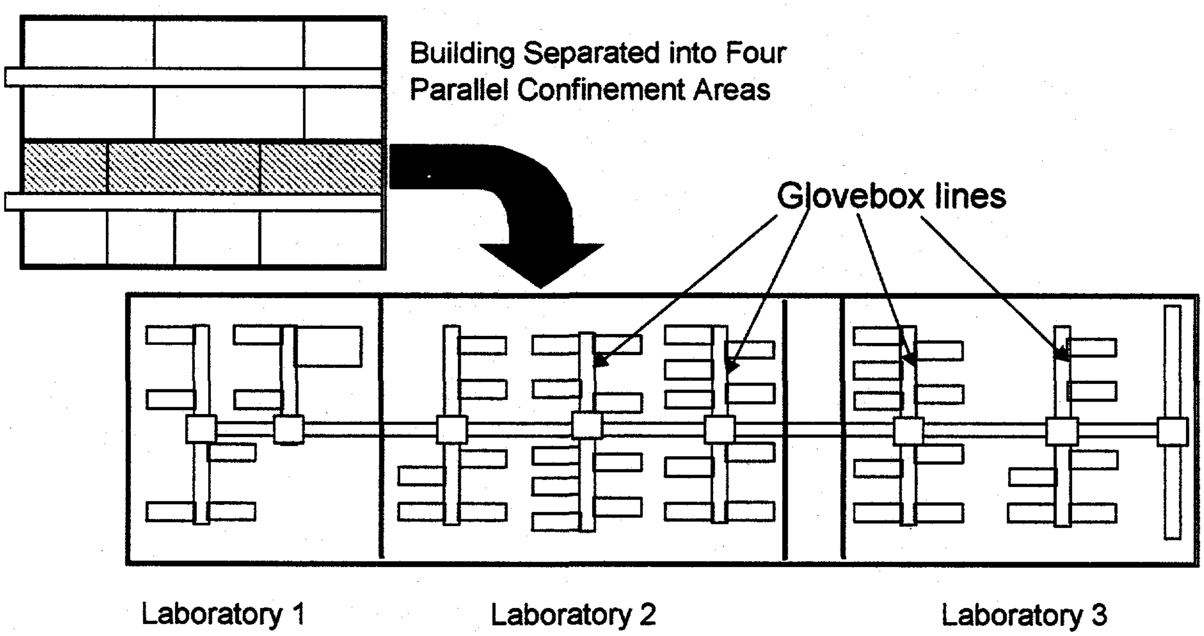


Fig. 1. Location of Drop-Box Lines Represented in the MELCOR Model

calculate fluid flow, heat transfer, thermodynamics, and transport of airborne contaminants (aerosol and vapor) are readily adaptable to the evaluation of upset conditions in DOE facilities. The general utility of MELCOR for these purposes initially was noted by a working group of safety analysts from several DOE laboratories [2]. Since then, the code has been used extensively to calculate building leak-path factors (LPFs) for fire accident scenarios in highly compartmentalized buildings [3,4].

**MELCOR Model of PF-4 Glovebox System**

The manner in which the PF-4 glovebox system was subdivided into MELCOR control volumes is shown in Fig. 2. Each glovebox, trunkline, and drop box is modeled as a unique control volume. The main conveyor tunnel was subdivided into several linked control volumes separated at the location of intervening drop boxes. Air flow between neighboring control volumes is modeled through the definition of MELCOR flow paths (shown as arrows in Fig. 2). The mechanical fire dampers installed at the base of each drop box also are modeled, with appropriate control logic to close the corresponding flow paths when actuation criteria are met. The walls and floors of these structures are modeled using actual material properties and dimensions. An illustration of the resulting MELCOR model of typical drop-box lines in a single laboratory is shown in Fig. 3.

The connection of these components to the other major elements of the glovebox ventilation system is shown in Fig. 4. Ductwork for glovebox ventilation supply and exhaust lines are modeled, including a control volume for the exhaust plenum. HEPA filters are modeled in their correct locations, including

- the exhaust lines from each glovebox,
- the inlet to the supply header in the building basement, and
- the exhaust plenum.

These filters currently are modeled as single-stage, particulate filter media. Flow rates throughout the model are controlled by fans, which are modeled in the glovebox and laboratory ventilation exhaust lines.

**Validation of Model**

Nominal values for ventilation system flow rates and local pressures are monitored and documented in informal data bases maintained by the ventilation system engineer. The MELCOR model of the glovebox system was exercised under nominal steady-state operating conditions running a 'transient' calculation in which no hypothetical accident perturbations are introduced. Under such conditions, the model will quickly establish an equilibrium flow and pressure distribution throughout the system, which is maintained by the operation exhaust fans in accordance with their specified flow/head curves. This exercise is analogous to starting-up the ventilation system and letting it naturally achieve a stable operating state.

The flow rates and pressures at key locations in the system calculated by MELCOR then were compared with facility operating data as an indication of whether the model is capable of reasonable simulation of actual system behavior. The calculated values were well within the tolerances of the actual or target values.

## GLOVEBOX FIRE SIMULATIONS

The model described above was used to examine the response of various components of a typical drop-box line to a spectrum of postulated glovebox fire accident scenarios. Examples of such components and the questions these calculations are intended to address are listed below:

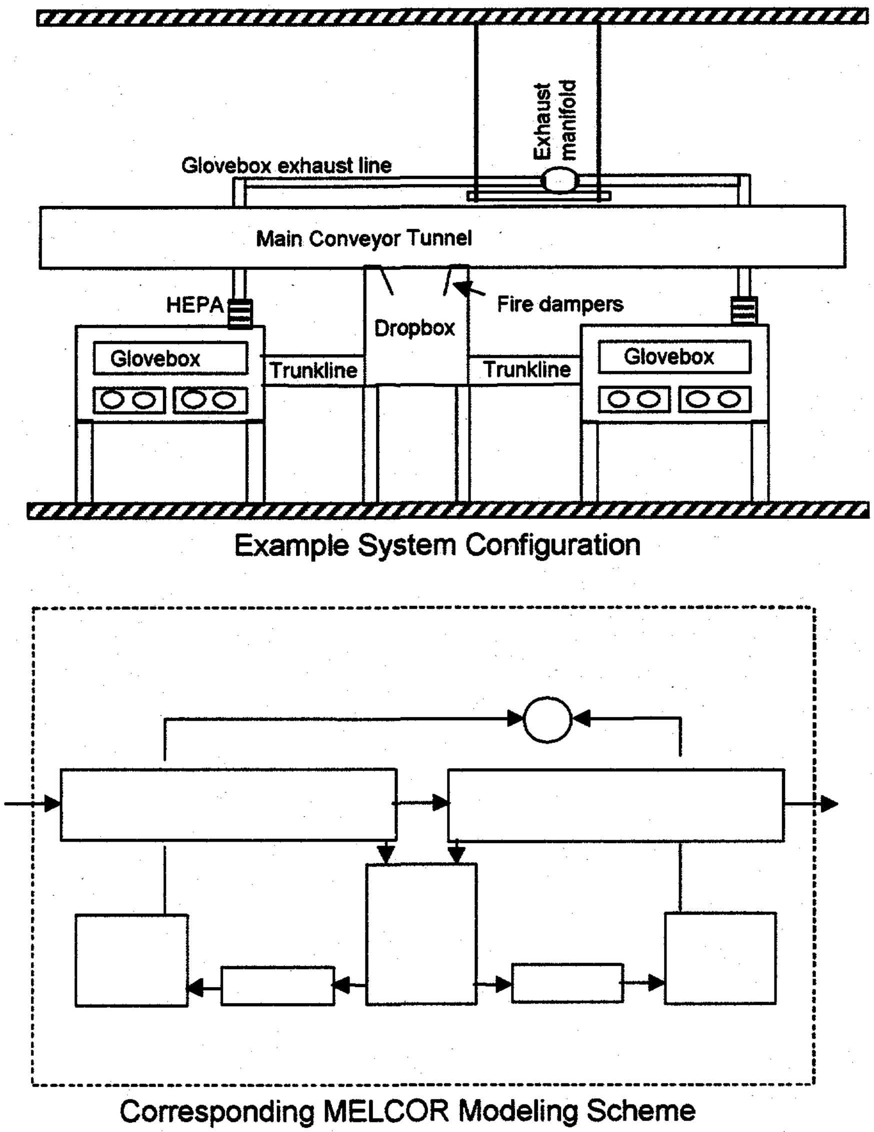


Fig. 2. Typical Drop-Box Line and Corresponding MELCOR Nodalization Scheme

- *Neighboring gloveboxes.* Under what conditions might a fire originating in a single glovebox propagate to neighboring gloveboxes?
- *Drop boxes.* How important are the drop-box fire dampers to controlling fire propagation beyond the drop-box line?
- *Ventilation system.* Does continuous operation of Zone 1 ventilation significantly influence system response to a glovebox fire?
- *Laboratory response.* What temperatures do the room housing the drop-box line 'see' during a glovebox fire?

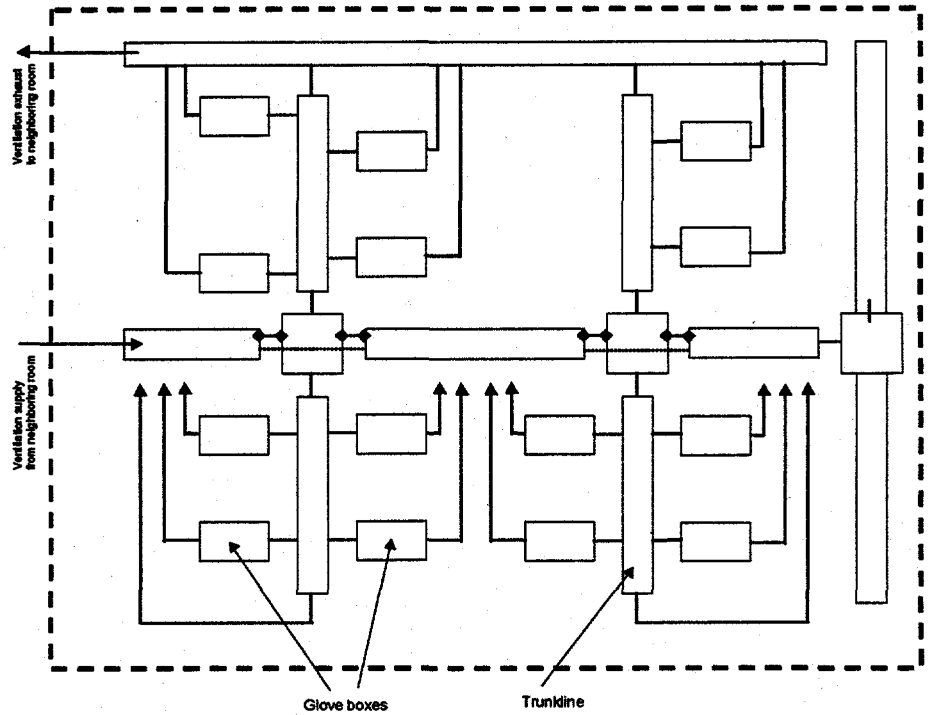


Fig. 3. MELCOR Nodalization of Drop-Box Lines in a Single Laboratory

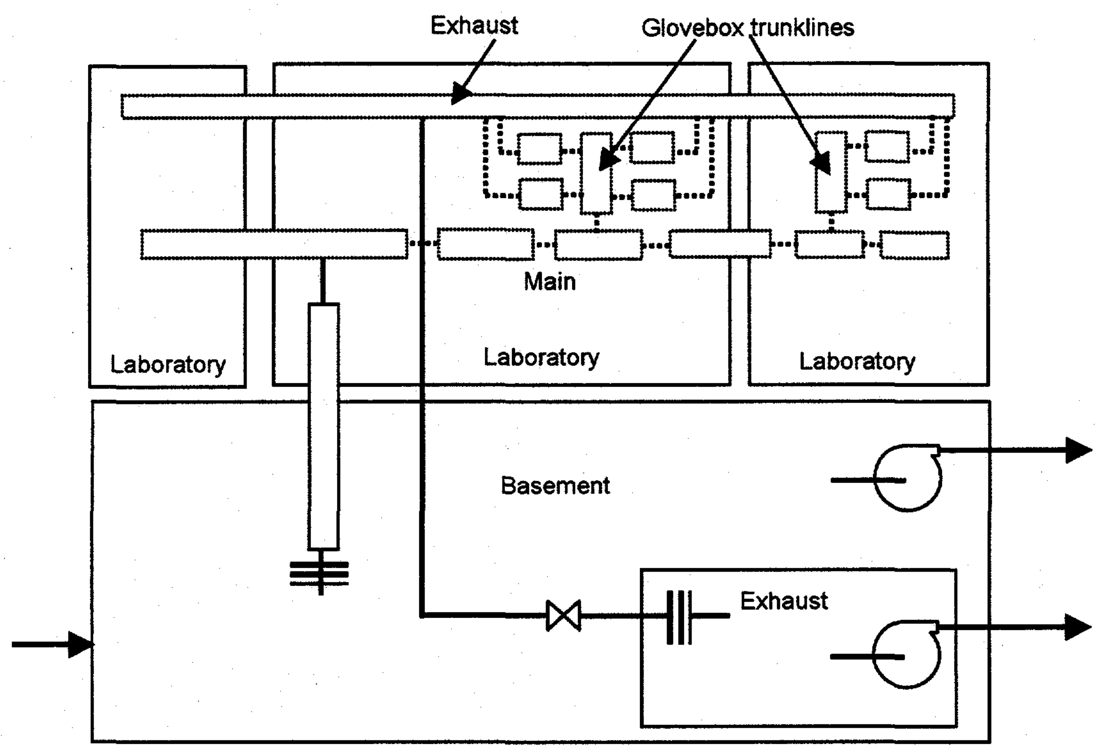


Fig. 4. Connectivity Between Laboratory Drop-Box Lines and Major Ventilation System Components

**Parameters Examined in the Calculations**

Because of the diversity of glovebox configurations and contents in PF-4, several calculations were performed to consider plausible variations in the following.

- *Combustible materials*. In addition to ordinary combustibles (such as Kimwipes and other cellulose trash), fires involving flammable liquids (solvents) and pyrophoric metals were examined.
- *Combustible loading*. The total quantity of combustible materials was varied over a wide range to determine its effect on system response.
- *Safety system operation*. The possibility that selected safety systems might fail to operate as designed was considered. In particular, cases were examined in which drop box fire damper failed to close and/or ventilation system(s) were inoperative. Failure of glovebox confinement was also examined by considering the loss of glove or glovebox window seal integrity at high temperature.
- *Energetics of the fire*. The rate at which combustible materials are consumed (i.e., pyrolyzed) by fire can vary considerably, with strong dependence on material geometry, degree of compaction, availability of oxygen, and other factors. These factors were treated parametrically in the calculations.
- *Number of gloveboxes open to dry air ventilation*. The number of gloveboxes open to the dry air ventilation system not only varies from room to room but can vary with time within a given room. System response to a glovebox fire was examined for the extreme cases of a minimum of two open gloveboxes in a single drop-box line, to all gloveboxes being open.

**Glovebox Fire Characteristics**

The characteristics of a fire that might occur in a process glovebox are a strong function of the combustible material involved. For the purposes of this analysis, three general classes of materials were considered.

- Ordinary combustibles (cellulose)
- Flammable liquids
- Pyrophoric metals

The combustion properties of these materials span a wide range and, in each case, were applied only when sufficient oxygen was present in the affected glovebox to support burning of the fuel. The consumption of oxygen and the corresponding release of combustion gases also were represented in the model in the form of mass sources and sinks.[1] Flow in or out of the glovebox containing the fire allows oxygen levels to be replenished. However, if the depletion of oxygen resulting from the fire exceeds the net flow into the glovebox from neighboring control volumes, the local oxygen level decreases. If the local oxygen level decreases below an assumed lower flammability limit, combustion of fuel is terminated temporarily until fresh air flows back into the glovebox. As noted below, this tends to produce a cyclic 'breathing' behavior for many postulated fires.

**Baseline Glovebox Fire Calculation**

A baseline calculation was performed using the following assumptions.

- All gloveboxes are open to the glovebox dry air ventilation system, which operates normally throughout the accident.

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1 The rate energy addition to a 'burning' glovebox is tied to the control variables for the combustion mass balance.

- A fire involving ordinary combustible materials ignites in a single glovebox 60 s into the calculation.
- The heat-release rate from the fire increases linearly from 0 to 100 kW over the next 60 s, then remains constant for the duration of the simulation (subject to availability of adequate oxygen).
- Gloves in the burning glovebox are assumed to fail (i.e., melt) if the temperature inside the glovebox exceeds 100°C.
- All energy generated by the fire is assumed to be deposited directly to the glovebox atmosphere. Radiative heat losses from the flame to the walls of the glovebox are not taken into account.[2] Convective heat transfer from the atmosphere to bounding structures is modeled.
- Fire dampers located in the drop box attached to the affected trunkline are assumed to remain fixed in the open position throughout the accident.[3]
- Glovebox ventilation operates normally.

The calculated quantity of fuel consumed by this fire is shown in Fig. 5. Approximately 5 lb of material is burned in the first 10 min of the fire (i.e., a pyrolysis rate of approximately 0.47 lb/min). This burn rate is lower than the maximum rate of 0.72 lb/min, indicating constraints in oxygen availability. This observation is confirmed in Fig. 6, which shows the calculated oxygen concentration in the affected glovebox. The local oxygen concentration decreases sharply following the start of the fire, and combustion byproducts, such as $CO_2$, are generated in its place (not shown in the figure). When the local oxygen concentration decreases below 8% (the assumed lower flammability limit), combustion ceases and the oxygen level briefly recovers as a result of replenishment of air from external sources. The glovebox oxygen concentration rapidly cycles above and below 8% for the remainder of the accident as the fire 'breathes' (i.e., consuming oxygen when available, then receding until air is drawn back into the glovebox).

The calculated temperatures in the glovebox are shown in Fig. 7. Atmosphere temperatures quickly rise above 1000°F, and stabilize at 1600–1800°F. The steel walls of the glovebox represent a significant heat sink for the fire, but increase in temperature a much slower rate.[4] The gloves penetrating the glovebox wall fail at temperatures significantly lower than those shown in Fig. 7, creating an opening between the glovebox and the laboratory room.

In addition to temperature response, changes in the rate or direction of air flow through the glovebox are an important aspect of glovebox fire accident scenarios. Of particular interest is the potential for sufficient energy to be transferred to neighboring gloveboxes or other regions of the confinement system to cause the fire to spread.

As shown in Fig. 8, dramatic changes take place in the flow in and out of the glovebox after the fire begins at 60 s. Before that point in time, air flows into the glovebox from the trunkline at a rate of approximately 20 $ft^3$/min, and is exhausted at the same rate through the glovebox exhaust line.

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2 This conservative assumption results in higher glovebox atmosphere temperatures than would be expected under actual conditions. Data for fires involving common fuels (e.g., petroleum, paper, etc.) show that typically 50–75% of the chemical energy generated by the fire is transferred directly to the surrounding atmosphere (via convection). The remainder is transmitted as radiant heat, directly from the flame to bounding structures.

3 The fire dampers normally would close upon receipt of an actuation signal triggered by a thermocouple mounted in the burning glovebox.

4 Accounting for radiative losses from the flame would increase glovebox wall temperatures and (for the same total energy release) decrease atmosphere temperatures.

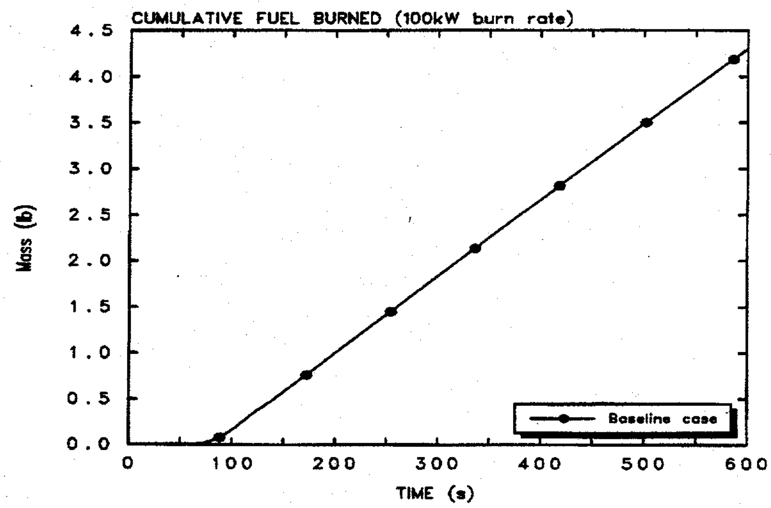


Fig. 5. Baseline Scenario: Cumulative Mass of Fuel Consumed in Fire

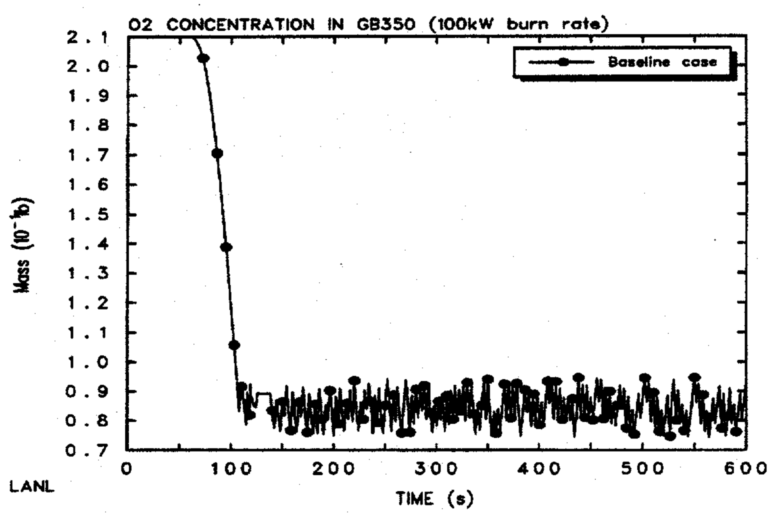


Fig. 6. Baseline Scenario: Oxygen Concentration in Burning Glovebox

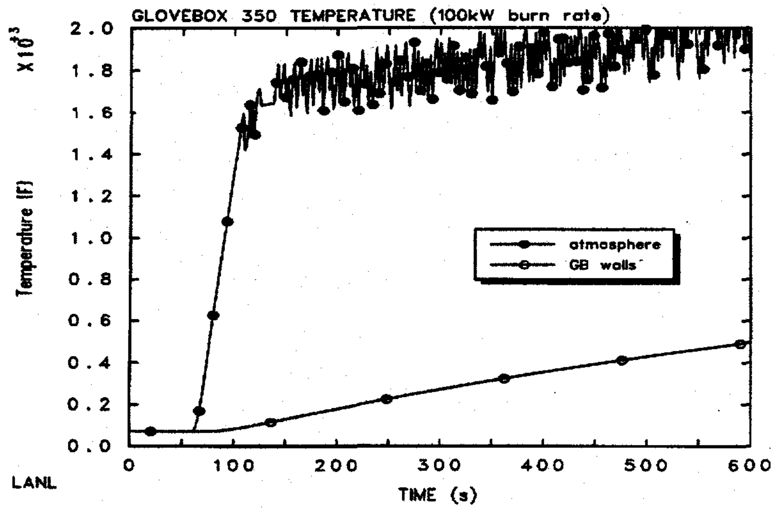


Fig. 7. Baseline Scenario: Atmosphere Temperature in Burning Glovebox

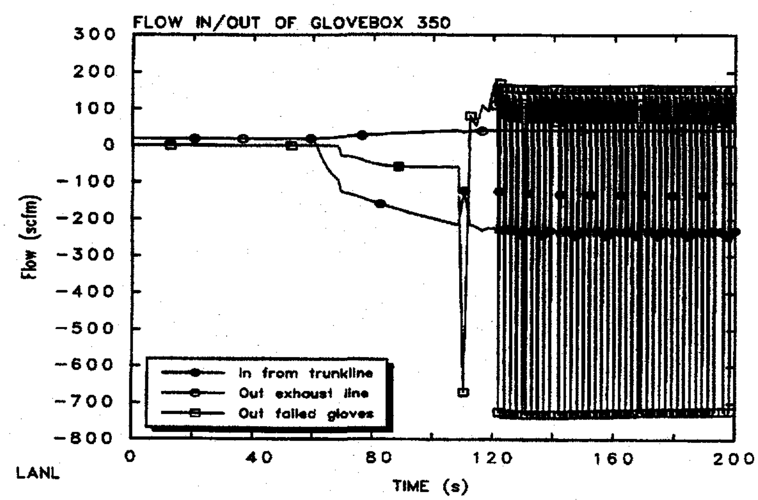


Fig. 8. Baseline Scenario: Flow Rates In/Out of Burning Glovebox

After 60 s, energy released by the fire causes the glovebox atmosphere to expand, forcing combustion gases to flow out through the doorway and into the trunkline. When the gloves fail (approximately 10 s later), air flows into glovebox through the open holes, driven by the differential pressure maintained by continued operation of the Zone 1/2 exhaust fans.

However, as shown in Fig. 6, the flow of air into the glovebox is not sufficient to replenish the air consumed in the fire. Oxygen levels within the glovebox slowly decline until the lower flammability limit is reached (approximately 110 s into the baseline calculation). Beyond that point in time, air flow becomes relatively unstable and a characteristic breathing cycle is established. That is, combustion gases are discharged from the glovebox during periods of intense burning, and the fire subsides when oxygen is depleted. Air then rushes into the glovebox, stoking the fire; the cycle repeats as long as fuel is available.

The effects of this flow behavior on gas temperatures in other regions of the glovebox system are shown in Fig. 9. Dilution of combustion gases released from the burning glovebox with air from the other ~50 gloveboxes in the area greatly reduces the bulk temperature of gases arriving in the Zone 1 ventilation system exhaust plenum. For this particular accident scenario, the exhaust plenum temperature increases by only 10°F. Gloveboxes immediately adjacent to the burning glovebox experience a small increase in temperature as air is drawn into them from the heated trunkline. However, the temperature increase is calculated to be very small (only 10°F for a 5-lb fuel load). Temperatures in the drop box and locations further away from the affected trunkline are essentially unaffected by the fire.

**Variations in the Single Glovebox Fire Scenario**

Alternative assumptions regarding the parameters listed above were examined by altering the boundary conditions used in the baseline calculation and recalculating the system response. The same base MELCOR model was used for all calculations. The results of calculations for two example variations in modeling assumptions are summarized below.

**Glove Failure**

The gloves used in PF-4 are made of Neoprene, Butyl, or Butasol rubber and may be leaded or unleaded, depending on the need for shielding and protection against chemical incompatibilities with

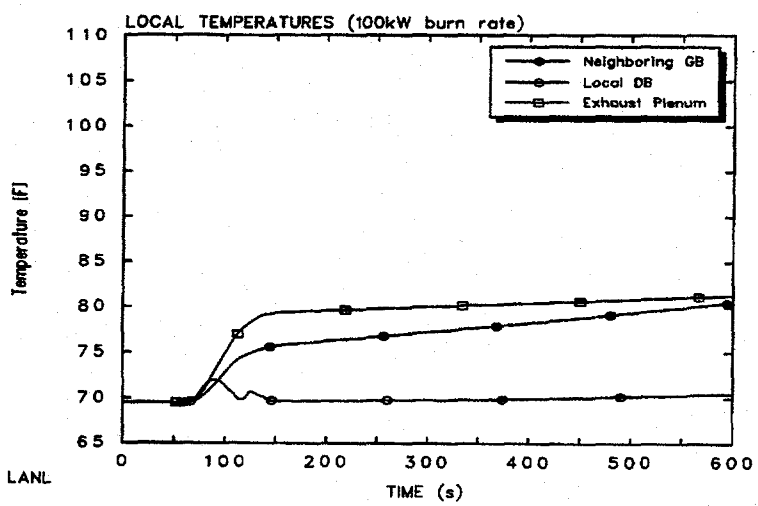


Fig. 9. Baseline Scenario: Atmosphere Temperatures at Locations Away from a Burning Glovebox

the processes performed in specific gloveboxes. The maximum service temperature for these materials is 225–300°F, well below the temperatures likely to be generated during the glovebox fires examined in this study. Consequently, mechanical failure of the gloves is assumed to occur in the baseline calculation described above and all subsequent calculations (except the one described in this section). Failure is assumed conservatively to occur when glovebox temperatures reach 100°C (212°F), creating an opening between the glovebox and the laboratory corresponding to the area of four 6-in.diam holes, i.e., 113 $in^2$ (0.073 $m^2$).

*Glovebox air flow*

As described above, the major effect of glove failure is to provide an alternative path by which air can enter the glovebox and feed the fire. If the gloves do not fail, the only pathway available for fresh air to enter the glovebox is through the trunkline access door. For the fire to be sustained, fresh air must be supplied and combustion gases much be exhausted through the access door[5]. Consequently, the flow through the access door exhibits the cyclic 'breathing' characteristic described earlier. This behavior is shown in Fig. 10, which compares the calculated flow rate through the access door for the cases with and without glove failure.

The effect of this change in the overall flow pattern and net flow through the glovebox as a result of glove failure is best illustrated by examining the cumulative (i.e., integral) volume of all gases that pass through the three entry/exit pathways at the glovebox boundary. Figure 11 compares these flows for the cases with and without glove failure. In this figure, 'positive' values represent flow into the glovebox through the open access doorway, out of the glovebox through the normal exhaust line, and out of the glovebox through the (failed) glove ports. Before the start of the fire (at 60 s), the total flow into the glovebox through the open door is matched by the flow out through the exhaust line (with a net throughput of approximately 20 $sft^3$/min). However, after the fire begins, the flow pattern changes dramatically.

In the sensitivity calculation (without glove failure), the exhaust line essentially is removed from the problem, and flow through the glovebox is controlled by the cyclic breathing of gases in and out of the trunkline access door. The net flow through this path is near zero in the long term, indicating that virtually all air drawn into the glovebox is consumed in the fire and then expelled through the same flow path (although in the reverse direction). Failure of the gloves in the baseline calculation occurs at approximately 70 s and generates a very different flow pattern. Air is drawn into the glovebox (negative net flow in Fig. 11) through the failed gloves, and combustion gases flow out of the glovebox (negative net flow in Fig. 11) through the open trunkline access door. Again, the normal exhaust line plays a minor role in the overall gas exchange.

One effect of the enhanced supply of air to the glovebox after glove failure occurs is an increase in the burn rate of fuel. However, the difference in burn rate is not calculated to be as large as one might expect. The enhanced air flow through the failure gloves increases the fuel consumption rate by approximately 10%.

*Glovebox temperatures*

The increased flow of air into the burning glovebox accompanying glove failure causes an increase in glovebox atmosphere temperature (Fig. 12). Despite significant differences in the general characteristics of this flow (with vs without glove failure),[6] the net effect on temperatures in

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[5] The flow resistance through the exhaust line is generally too high to provide a major contribution to the overall gas flow during a fire

[6] A relatively steady flow out of the glovebox access door was observed in the baseline calculation vs a highly oscillatory flow in the case with glove failure.

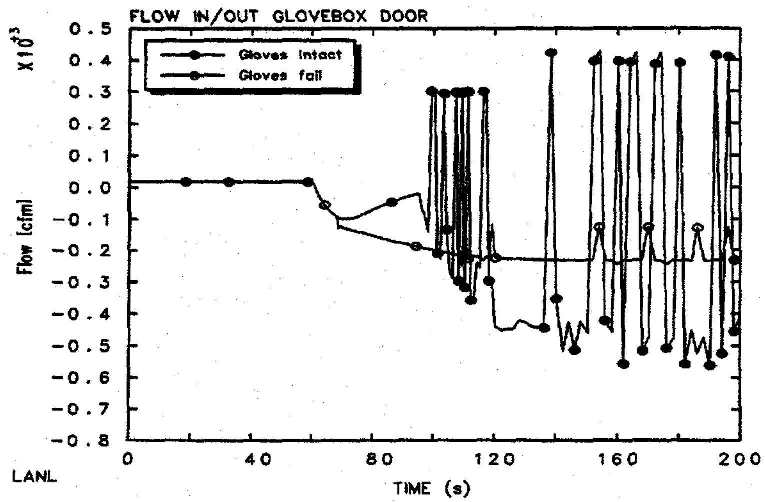


Fig. 10. Sensitivity Calculation: Flow In/Out of Glovebox Access Door (With and Without Glove Failure)

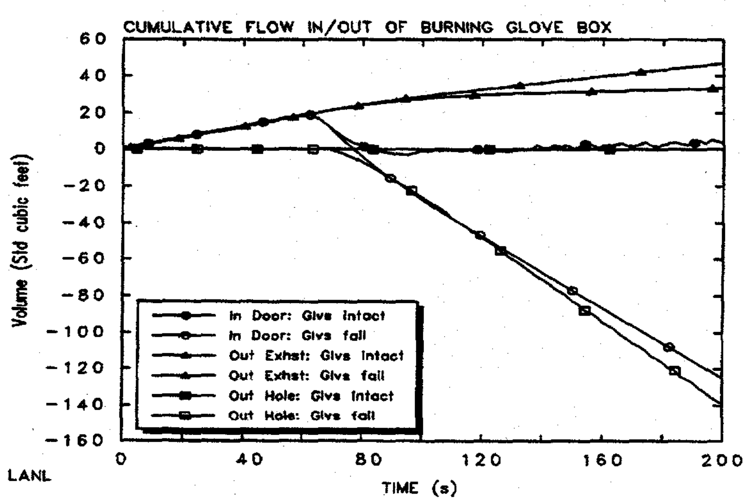


Fig. 11. Sensitivity Calculation: Cumulative Flow In/Out of Burning Glovebox (With and Without Glove Failure)

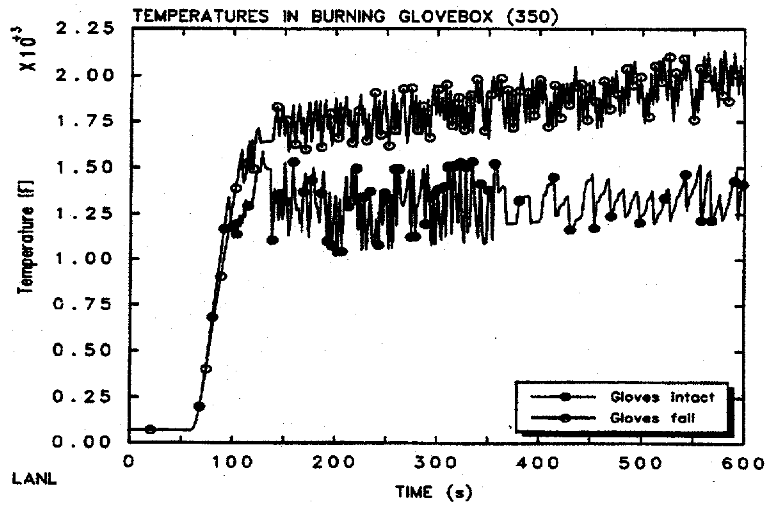


Fig. 12. Sensitivity Calculation: Temperature in Burning Glovebox (With and Without Glove Failure)

neighboring gloveboxes is quite small. This is because combustion gases were calculated to flow out of the glovebox and into the trunkline in both cases. As shown in Fig. 13, the air temperature in other gloveboxes connected to the same trunkline as the one containing the fire increases by only 10°F over first 10 min of the fire.[7] Gloveboxes attached to the trunkline attached to the opposite side of the affected drop box experience a negligible temperature increase (<2°F) over the same period.

*Temperatures at other locations*

Remote portions of the Zone 1 ventilation system are affected by the heat generated in the burning glovebox but only to a limited extent. Dilution of hot combustion gases released from a single burning glovebox with the cooler, unheated gases released from the other (up to 50) gloveboxes using the same ventilation system greatly reduces temperatures far downstream of the burning glovebox. Of particular interest is the temperature of gases passing through the exhaust plenum, where the exhaust HEPA filters are located. Temperatures at this location were calculated to increase by less than 12°F over the first 10 min of the fire.[11]

Atmosphere temperatures in the laboratory containing the burning glovebox are also of interest. Room temperature is affected by two heat-transfer mechanisms. The first is simple heat transfer through the hot walls of the glovebox. This mechanism is rather slow but not entirely negligible when the glovebox walls reach very high temperatures. The second is the transport of hot gases from the glovebox into the room through failed glove ports. As described above, the pressure differential maintained between the gloveboxes and laboratories causes the flow of gases through failed glove ports to the primarily <u>into</u> the glovebox (not outward). Further, active Zone 2 ventilation provides an average of 6 to 7 air changes per hour in the room, which slows the rate of room heat up by dilution of the room air with cooled, fresh air. The net result of all these effects is a room temperature rise of approximately 5°F over the first 10 min of the glovebox fire[11] with glove failure and 3°F without glove failure.

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[7] A 10-min fire consumes 4–5 lb of a cellulose fuel (see Fig. 4.3).

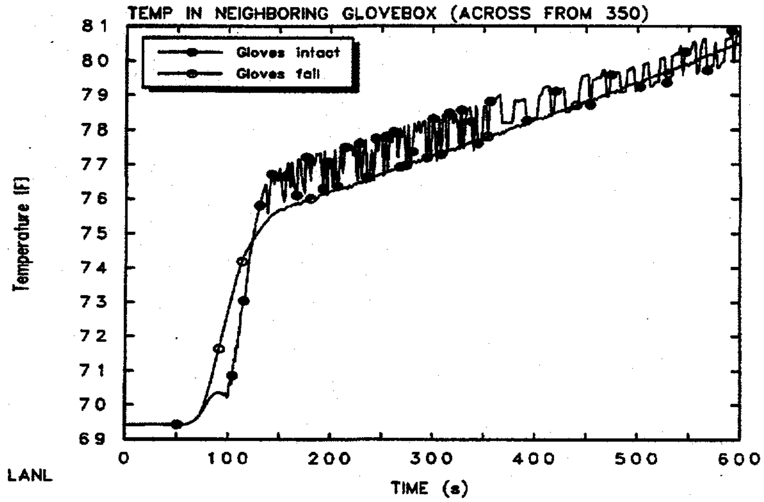


Fig. 13. Sensitivity Calculation: Temperature in Glovebox Adjacent to Burning Glovebox (With and Without Glove Failure)

**Zone 1 Ventilation Flow (exhaust fan failure)**

Operation of the Zone 1 ventilation system provides the sole driving force for maintaining negative pressure in gloveboxes. Consequently, changes in glovebox fire behavior associated with coincidental failure of ventilation flow are of interest. A sensitivity calculation was performed in which the Zone 1 ventilation exhaust fans were assumed to stop running before the fire ignites in the glovebox.[8] For the reasons described above, gloves were assumed to fail when glovebox temperatures exceeded 100°C.

The calculated effect of inactive ventilation exhaust fans on glovebox pressure is shown in Fig. 14. Operation of the exhaust fans maintains glovebox pressure at approximately –0.5 in. of water column (in.-WC) relative to the laboratory. In the case where the exhaust fans are assumed to fail, this differential pressure gradually decreases to 0 as the exhaust fans coast down during an assumed 30-s period. The other case shown in this figure assumes continuous operation of the Zone 1 exhaust fans, thereby allowing glovebox pressure to remain stable until the fire begins. Energy released by the fire (beginning at 60 s) causes the glovebox pressure to increase by 0.2 to 0.3 in.-WC with or without the exhaust fan running. When the gloves fail at 70 s, pressure in the burning glovebox equilibrates with the laboratory with or without active Zone 1 ventilation.

Termination of forced flow through the gloveboxes does not mean flow in the burning glovebox completely stops. The 'breathing' behavior described above continues without exhaust fan operation. [The calculated flow rates through the open trunkline access door, and through the failed glove ports are shown in Figs. 15 and 16, respectively (with and without active Zone 1 ventilation).] However, without forced ventilation (exhaust) flow, the transport of combustion gases away from the burning glovebox is confined to the laboratory housing it. Locations distant from the burning glovebox are not 'aware' of the fire.

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8 For modeling purposes only, the fan speed was ramped down from nominal values to zero starting at time = 0.0 and terminating 30 s later. As in previous calculations, the fire was assumed to ignite at time = 60 s.

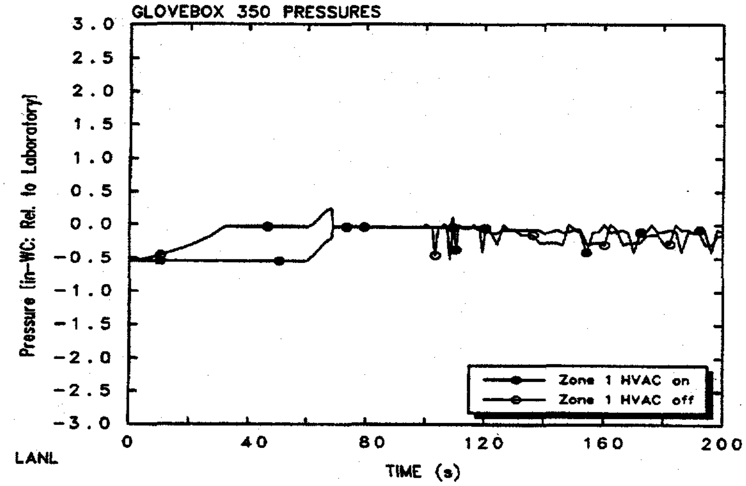


Fig. 14. Sensitivity Calculation: Pressure in Burning Glovebox (Zone 1 Ventilation On vs Off)

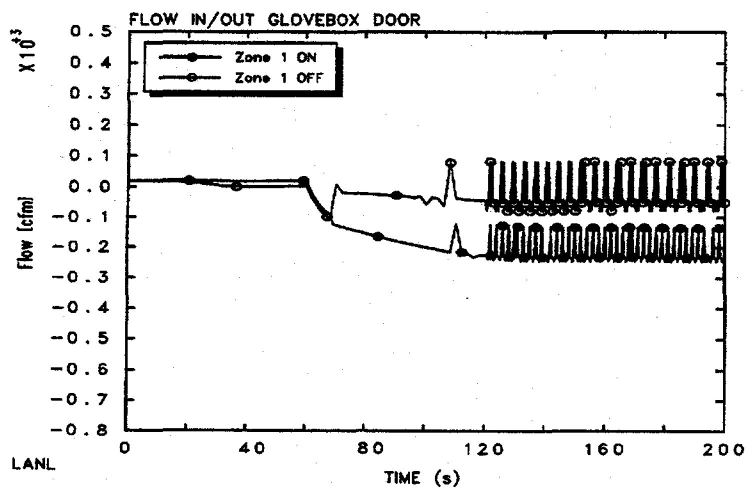


Fig. 15. Sensitivity Calculation: Flow In/Out Glovebox Access Door (Zone 1 Ventilation On vs Off)

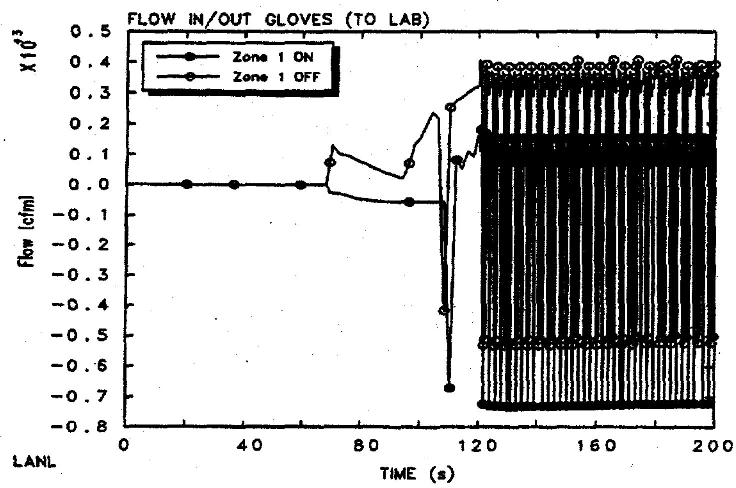


Fig. 16. Sensitivity Calculation: Flow In/Out Glove Ports (Zone 1 Ventilation On vs Off)

This effect is evident in a comparison of the glovebox and laboratory temperatures with and without ventilation. Temperatures in the burning glovebox are unaffected by the loss of active glovebox ventilation (Fig. 17). However, the loss of active glovebox exhaust flow causes a larger fraction of the combustion gases to be exhausted to the laboratory through the failed glove ports, resulting in a noticeable increase in room temperature[9] (Fig. 18). Loss of glovebox exhaust flow decreases the pressure gradient between the burning glovebox and other neighboring gloveboxes, thereby reducing the flow rate of combustion gases out of the open trunkline access door (shown in Fig. 15). Consequently, the temperature increase observed by neighboring glovebox is even smaller than that calculated for the baseline case (see Fig. 19).

## CONCLUSIONS

Propagation of a fire that originates in a single glovebox to other locations in PF-4 is conceivable only if transport of hot combustion gases to other locations causes ignition of combustible materials elsewhere in the system (i.e., flashover). Therefore, a model of the PF-4 glovebox system and associated Zone 1 ventilation system in PF-4 was developed to calculate the movement of combustion gas mass and energy during postulated glovebox fire accident scenarios. The model was developed using the MELCOR computer code, which has been used for other evaluations of DOE facility safety analysis issues.

A wide range of glovebox operating and potential fire conditions were examined to determine whether flashover conditions could occur at locations outside the burning glovebox.

- A variety of combustible material characteristics was considered (e.g., type of combustible material, quantity, and combustion properties).
- A spectrum of safety system operating conditions was considered (e.g., glovebox ventilation system operating normally vs an inoperative exhaust fan; drop-box fire damper closure vs failure to close).

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9 This increase is noticeable but not sufficient to raise concerns about flashover.

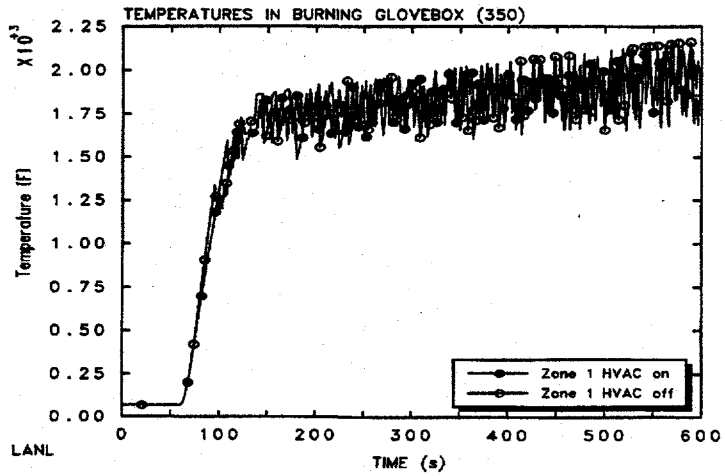


Fig. 17. Sensitivity Calculation: Temperatures in Burning Glovebox (Zone 1 Ventilation On vs Off)

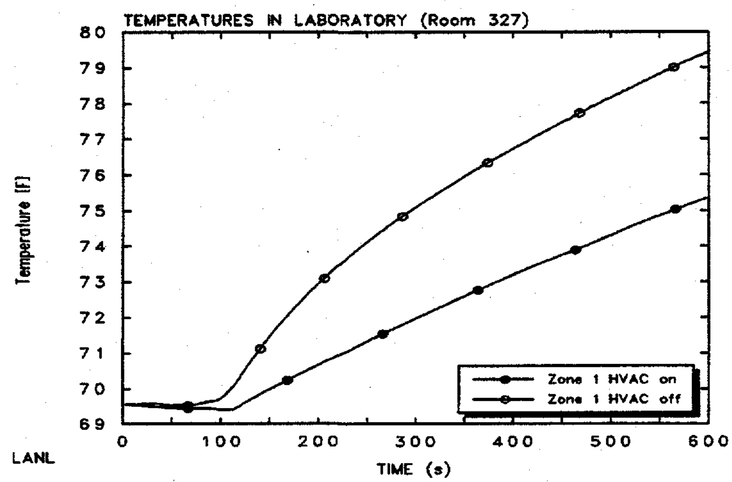


Fig. 18. Sensitivity Calculation: Temperatures in Laboratory (Zone 1 Ventilation On vs Off)

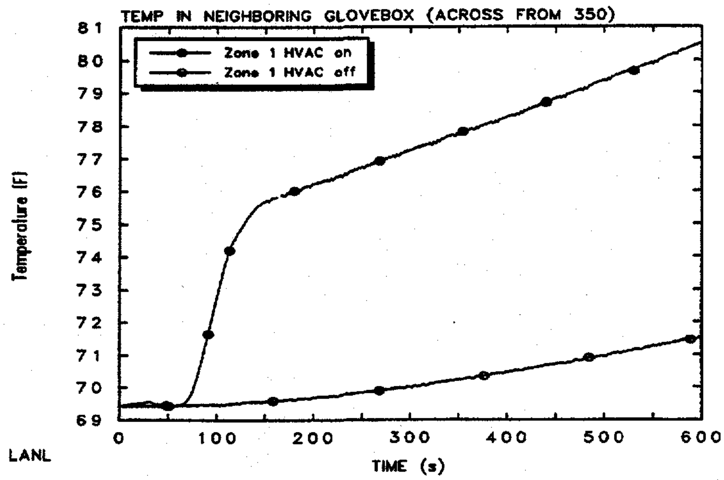


Fig. 19. Sensitivity Calculation: Temperatures in Glovebox Adjacent to Burning Glovebox (Zone 1 Ventilation On vs Off)

- A range analytical modeling assumptions was considered (e.g., the extent to which heat transfer between hot combustion gases and the glovebox walls is represented in the model).

Over 30 calculations were performed to examine various combinations of these variables and their effect on glovebox fire behavior.

None of the glovebox fire accident calculations predicted temperatures that approached typical flashover conditions (>600°F) in critical locations such as neighboring gloveboxes, drop boxes, or ventilation system exhaust plena. Consequently, the results of this analysis suggest that propagation of a fire outside the glovebox of origin as a result of transport of hot combustion gases is extremely unlikely. This conclusion also was found to hold for propagation of fires ignited simultaneously in multiple gloveboxes. Such a scenario is conceivable during certain seismic events. The results of a simulation for an extreme case of such an event indicates the temperature in the room housing the burning gloveboxes does not reach flashover conditions nor do temperatures in gloves boxes in the adjacent room.

## REFERENCES

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